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# James Hall Vegetated Roof Nutrient Removal Efficiency and Hydrologic Response

Robert Roseen
*University of New Hampshire*

Thomas P. Ballestero
*University of New Hampshire*, tom.ballestero@unh.edu

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## Basic Information

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|---|---|
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# James Hall Vegetated Roof Nutrient Removal Efficiency and Hydrologic Response, Final Report, April 2014

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*Report Authors*

James Houle, Program Manager
Timothy Puls, Field Facility Manager
Dr. Thomas P. Ballestero, Director

The UNH Stormwater Center
35 Colovos Road
University of New Hampshire
Durham, NH 03824
Web: www.unh.edu/unhsc

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## Executive Summary

The University of New Hampshire Stormwater Center (UNHSC) has completed a six month field verification study of a green roof system installed on James Hall at the University of New Hampshire in Durham NH. Monitoring took place from July 2013 through November 2013. A total of nine storms were evaluated and runoff from the vegetated roof system was compared to runoff from an equally sized section of untreated rooftop from which performance characteristics were developed.

The overall project objective was to evaluate performance with respect to effluent water quantity and water quality as compared to runoff from a reference roof section. Water quantity was monitored at the effluent of each roof section at 5-minute intervals throughout each sampled event. Laboratory analyses were conducted by the UNH Water Quality Analysis Laboratory (WQAL) within the Department of Natural Resources & the Environment. Water quality samples were processed for the following parameters: Nitrate/Nitrite in water (NO3, NO2), Total Dissolved Nitrogen (TDN), Ammonium (NH4), Total Nitrogen (TN), Total Phosphorus (TP), and Phosphate (PO4).

Results indicate that this vegetated roof section provides limited benefits with respect to water quantity and water quality control. The vegetated roof system appears best suited to reduce peak runoff flows from the rooftop by filtering water through the pervious reservoir. Peak flows exhibited an overall average reduction of 27%, however overall volume reductions were not observed. For water quality parameters the vegetated roof system exhibited export of Nitrogen and Phosphorus. Average concentrations of dissolved organic nitrogen and total phosphorus were an order of magnitude higher in the vegetated roof outlet compared to the flat roof reference, while average phosphate concentrations were two orders of magnitude higher in the vegetated roof outlet compared to the flat roof reference. The vegetated roof system did show a capacity to remove dissolved inorganic forms of nitrogen (DIN: NO3, NO2, and NH4) removing 59% of the measurable DIN the most common ionic (bioavailable) forms of nitrogen in aquatic ecosystems.

Most promising is the vegetative roof systems buffering of dissolved oxygen (DO) and pH levels in effluent runoff. Average effluent levels from the vegetated roof system were 1.6 and 0.8 points higher for DO and pH respectively. While water quality and quality benefits are widely marketed as features of vegetated roof systems it is clear that attention to volume reduction and nutrient control are important elements of any discussion of vegetated green roof systems. Designs to enhance control of nutrients and volume retention should be carefully considered. Other elements of vegetated roof benefits not explored in this study such as carbon sequestration and energy efficiency may be ancillary benefits that trump water quantity and water quality concerns.

## Site Description

James Hall underwent renovations that were completed in 2010 to become the first LEED (Leadership in Energy and Environmental Design) Gold certified building on the University of New Hampshire Durham campus. One of the sustainable innovations incorporated into the design is a gray water system that collects rainwater from the building’s roof for use in the toilets. One section of the roof was outfitted with a 400ft$^2$ modular vegetated roof system designed to capture and treat direct rainfall before draining into the gray water system. Adjacent to the vegetated roof section is an equally sized conventional rubber roof that serves as the comparative control for monitoring and research purposes. Both roof sections have independent roof drains leading into the gray water piping network within James Hall. This side-by-side design allows researchers to evaluate the water quality and hydrologic performance of the system.

The vegetated roof is comprised of 100 plastic modular trays that are 2ft square by 4in deep. The trays are filled with a mixture of chipped stone (3/8in chip shale) and loam, and planted with a variety of succulents. Many vegetated roof systems utilize succulents because they thrive in extreme arid climates through their ability to store water over long periods. Roof tops provide an ideal environment for these plants due to the inconsistency of rainfall patterns and elevated temperatures. Under the trays is a non-woven geotextile fabric that protects the conventional rubber roof from plant roots and other protrusions that could potentially damage the underlying impermeable layer. The roof section is pitched to the center of the 20ft by 20ft square where a roof drain is located. An adjacent conventional flat roof has the exact same dimensions and layout in order to provide an apples-to-apples comparison.

## Project Overview

This research provides a greater understanding of the treatment capacity of vegetated roofs for nitrogen (N) and phosphorous (P) runoff from flat roof structures. These constituents play a major role in the health of our urbanized surface waters and understanding the removal efficiency of vegetated roofs in a cold climate setting plays an important role in the future of non-point source pollution control. Hydrographs for storm events, snow/ice melt and drain down periods were obtained to determine the hydrologic function of the vegetated roof. This hydrologic data ties in a water balance and a rainfall-runoff relationship to compare with the treatment efficiency of the vegetated roof.

Objective: The University of New Hampshire Stormwater Center (UNHSC) in collaboration with the Natural Resources Department faculty and staff examined the water quality and hydrologic performance of a conventional rubber roof and vegetated roof system.

## Water Quality Monitoring

### Sample Analysis

Analytical testing of water samples consisted of Nitrate + Nitrite, Ammonium, Total Dissolved Nitrogen, Total Nitrogen, Phosphate, and Total Phosphorus. Analytes and methods are listed in Table 1. Analytical and methods procedures are outlined in the UNHSC Quality Assurance Project Plan, which can be made available upon request.

**Table 1: Analytes and Analytical Methods**

| ANALYTE | METHOD |
|---|---|
| Nitrate/Nitrite in water | EPA 353.2 |
| Total Dissolved Nitrogen (TDN) | High temp oxidation w/ chemiluminescent detection |
| Ammonium | EPA 350.1 |
| Total Nitrogen + Total Phosphorus | Resource Investigations Report 03-4174 |
| Phosphate | EPA 365 |

### Methods and Sampling

Monitoring of roof runoff was facilitated through the use of existing drainage infrastructure within James Hall. Water quality samples and real-time hydrologic monitoring data were collected in order to evaluate the differences between the vegetated green roof and conventional rubber roof sections. Storm event monitoring was conducted through summer and fall of 2013 over a wide range of rainfall characteristics (i.e. rainfall depth, rainfall intensity, storm duration, and antecedent dry period) (see Table 2). Automated sampling and monitoring equipment was installed to sample from the roof drain systems independently. The samplers were programmed to sample 100 milliliter aliquots at flow-weighted intervals into 1 liter containers. The samplers have a 24 x 1 liter bottle capacity which allows for a maximum of 240 samples per event. The sampling program is designed to ensure adequate coverage of the storm event and is adjusted to accommodate seasonal fluctuations in rainfall patterns.  Rejection criteria included minimum rainfall depth of 0.1 inches, minimum of 10 aliquots per sampling event, and at least 70% coverage of the total storm volume.

After the storm event the data was collected and samples were transported to the UNHSC field facility for post-processing. The flow-weighted samples were composited into identical 1 liter samples which are further processed into two 60ml sub-samples. One 60ml sub-sample was filtered through glass microfiber filters with 1.0µm pore size and the other 60ml sub-sample is unfiltered. The samples are then frozen until delivery to the UNH Water Quality Analysis Laboratory (WQAL) within the Department of Natural Resources & the Environment.

### Equipment

Teledyne ISCO 6712 Portable samplers (Figure 1) were used to monitor hydrology and take water quality samples during storm events.  Each sampler was outfitted with an ISCO 730 Bubbler module to continuously monitor water depth throughout each rain event. Using programmable features of the 6712 the monitored water depth was instantaneously computed into flow using Mannings' equation. Flow values are used to quantify runoff volumes which help to determine flow-weighted intervals. The samplers are equipped with twenty-four 1 liter sample bottles lined with disposable LDPE liners to ensure integrity of each sample. Rainfall was recorded using an ISCO 674 Rain Gauge located at the UNHSC field facility approximately 1 mile from the study site. The 1 liter composite samples are generated using a USGS Decaport Cone Splitter and sample splitting matrix developed by UNHSC research staff. Whatman Glass Microfiber Filters were used for processing the filtered s

**Figure 1: ISCO Portable Sampler with 6712 programmable control head.**


## Results

A total of 9 storm events were sampled between July and November of 2013. Table 2 lists the storm dates and respective storm hydrologic characteristics for each sampled event. Total storm depths ranged from 0.12 inches to 2.98 inches and peak rainfall intensities ranged from 0.12 inches per hour to 2.16 inches per hour. This demonstrates a wide range of sampled events over the course of the study period. Peak flows from each roof drain are also listed to demonstrate the vegetated roof's capacity to reduce peak flows. All but one event showed a reduction in peak flow and the average peak flow reduction over the study period was 27%. There was no discernable difference in the total volume of runoff, nor was there any detectable effect of antecedent dry period. The second longest antecedent dry period (14 days) led to the largest negative discrepancy in runoff volume between the study and reference sites.

**Table 2: Summary table of storm event hydrologic characteristics for each monitored storm event.**

| Date | Duration (min) | Total Rainfall (in) | Peak Intensity (in/hr) | Antecedent Dry Period (days) | Veg Roof Peak Flow (gpm) | Flat Roof Peak Flow (gpm) | Peak Flow Reduction % | Veg Roof Total Volume (gpm) | Flat Roof Total Volume (gpm) | Volume Reduction % |
|---|---|---|---|---|---|---|---|---|---|---|
| 7/11/2013 | 1325 | 0.22 | 0.72 | 3 | 16.1 | 9.0 | -79% | 976 | 425 | -130% |
| 7/23/2013 | 1155 | 0.48 | 0.48 | 5 | 8.8 | 14.8 | 41% | 959 | 1072 | 10% |
| 8/1/2013 | 1095 | 0.53 | 0.48 | 7 | 5.2 | 9.7 | 46% | 492 | 1069 | 54% |
| 8/9/2013 | 4865 | 2.10 | 2.16 | 7 | 25.8 | 38.8 | 33% | 1912 | 2381 | 20% |
| 9/12/2013 | 2230 | 2.98 | 2.04 | 6 | 34.5 | 35.9 | 4% | 2418 | 2349 | -3% |
| 9/22/2013 | 1440 | 0.60 | 1.68 | 9 | 26.1 | 34.8 | 25% | 990 | 681 | -45% |
| 10/6/2013 | 1900 | 0.26 | 0.24 | 14 | 2.6 | 6.6 | 60% | 1311 | 383 | -242% |
| 10/31/2013 | 1240 | 0.12 | 0.12 | 22 | 1.8 | 2.2 | 18% | 546 | 373 | -47% |
| 11/17/2013 | 1370 | 0.27 | 0.48 | 7 | 1.0 | 10.5 | 91% | 108 | 873 | 88% |
| MIN | 1095 | 0.12 | 0.12 | 3 | 1.0 | 2.2 | -79% | 108 | 373 | -242% |
| AVERAGE | 1847 | 1 | 1 | 9 | 13.5 | 18.0 | 27% | 1079 | 1067 | -33% |
| MEDIAN | 1370 | 0.48 | 0.48 | 7 | 8.8 | 10.5 | 33% | 976 | 873 | -3% |
| MAX | 4865 | 2.98 | 2.16 | 22 | 34.5 | 38.8 | 91% | 2418 | 2381 | 88% |

Results of water quality monitoring for the 9 storm events are listed in Table 3 and Table 4 and displayed in box and whisker plots in Figure 2 through Figure 5. The data shows that the vegetated roof system exported Total Nitrogen (TN), Particulate Nitrogen, Total Dissolved Nitrogen (TDN), and Dissolved Organic Nitrogen (DON) for all of the sampled rain events. The removal efficiency for each pollutant was -216%, -1,034%, -170%, and -1,983% respectively. The results are similar for Phosphate (PO4) and Total Phosphorus (TP) showing average removal efficiencies of -15,450% and -3,273% respectively. The vegetated roof system demonstrated positive removal efficiencies for DIN species with Nitrate (NO3) + Nitrite (NO2) exhibiting an average removal rate of 33% and Ammonium (NH4) performance exhibiting an average removal rate of 84%.

**Table 3: Water quality monitoring results for the conventional flat roof and vegetated green roof including total nitrogen (TN), particulate nitrogen, total dissolved nitrogen (TDN), and dissolved organic nitrogen (DON) concentrations.**

| | TN (mg N/L) | | | Particulate-N (mg/L) | | | TDN (mg/L) | | | DON (mg N/L) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Veg Roof | Flat Roof | RE% | Veg Roof | Flat Roof | RE% | Veg Roof | Flat Roof | RE% | Veg Roof | Flat Roof | RE% |
| 7/11/2013 | 2.167 | 0.789 | -175% | 0.365 | 0.057 | -540% | 1.802 | 0.732 | -146% | 1.184 | 0.023 | -5151% |
| 7/23/2013 | 2.499 | 0.670 | -273% | 0.828 | 0.080 | -932% | 1.671 | 0.589 | -184% | 1.345 | 0.134 | -904% |
| 8/1/2013 | 2.652 | 0.503 | -428% | 0.150 | 0.006 | -2360% | 2.502 | 0.497 | -404% | 2.197 | 0.173 | -1170% |
| 8/9/2013 | 1.556 | 0.475 | -227% | 0.575 | 0.071 | -706% | 0.981 | 0.404 | -143% | 0.915 | 0.226 | -305% |
| 9/12/2013 | 1.134 | 0.713 | -59% | 0.367 | 0.190 | -93% | 0.766 | 0.522 | -47% | 0.705 | 0.053 | -1231% |
| 9/22/2013 | 1.459 | 0.238 | -513% | 0.377 | 0.014 | -2561% | 1.082 | 0.224 | -384% | 1.052 | 0.112 | -840% |
| 10/6/2013 | 1.189 | 1.014 | -17% | 0.026 | 0.088 | 71% | 1.164 | 0.926 | -26% | 0.993 | 0.141 | -605% |
| 10/31/2013 | 1.612 | 1.196 | -35% | 0.085 | 0.007 | -1148% | 1.527 | 1.189 | -28% | 1.277 | 0.022 | -5657% |
| | | | | | | | | | | | | |
| MIN | 1.134 | 0.238 | -513% | 0.026 | 0.006 | -2561% | 0.766 | 0.224 | -404% | 0.705 | 0.022 | -5657% |
| 25th Q | 1.392 | 0.496 | -312% | 0.134 | 0.012 | -1451% | 1.057 | 0.473 | -234% | 0.974 | 0.045 | -2211% |
| MEDIAN | 1.584 | 0.691 | -201% | 0.366 | 0.064 | -819% | 1.345 | 0.556 | -144% | 1.118 | 0.123 | -1037% |
| AVERAGE | 1.783 | 0.700 | -216% | 0.347 | 0.064 | -1034% | 1.437 | 0.635 | -170% | 1.209 | 0.110 | -1983% |
| 75th Q | 2.250 | 0.845 | -53% | 0.427 | 0.082 | -428% | 1.704 | 0.780 | -42% | 1.294 | 0.149 | -781% |
| MAX | 2.652 | 1.196 | -17% | 0.828 | 0.190 | 71% | 2.502 | 1.189 | -26% | 2.197 | 0.226 | -305% |

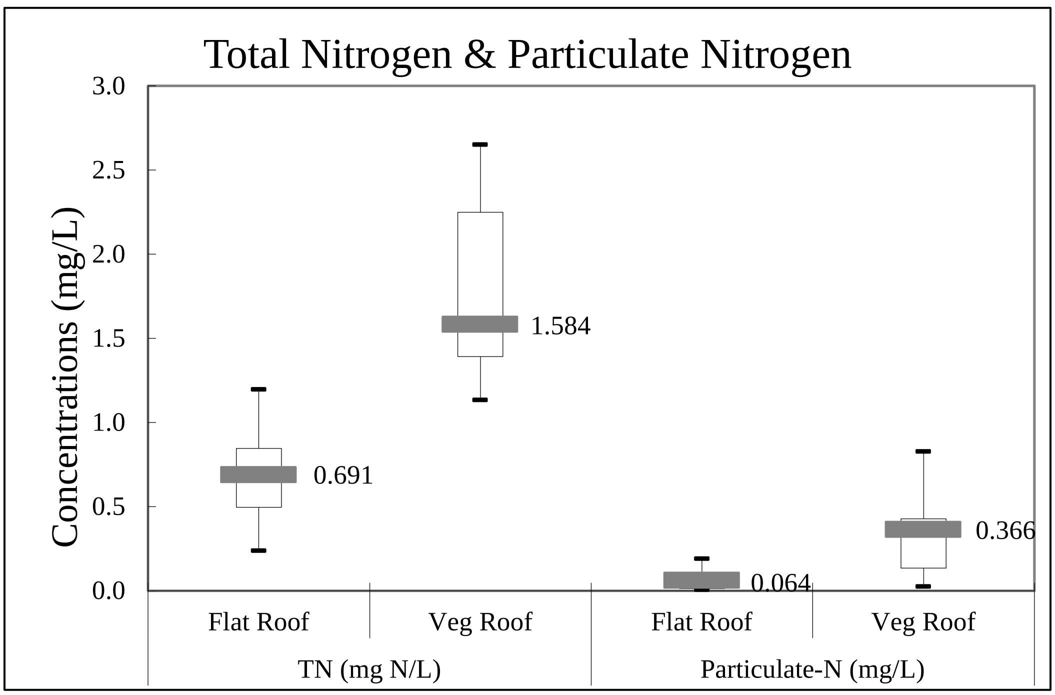


**Figure 2: Box and whisker plots of Total Nitrogen (TN) and Particulate Nitrogen results from conventional flat roof and vegetated green roof comparison study.**

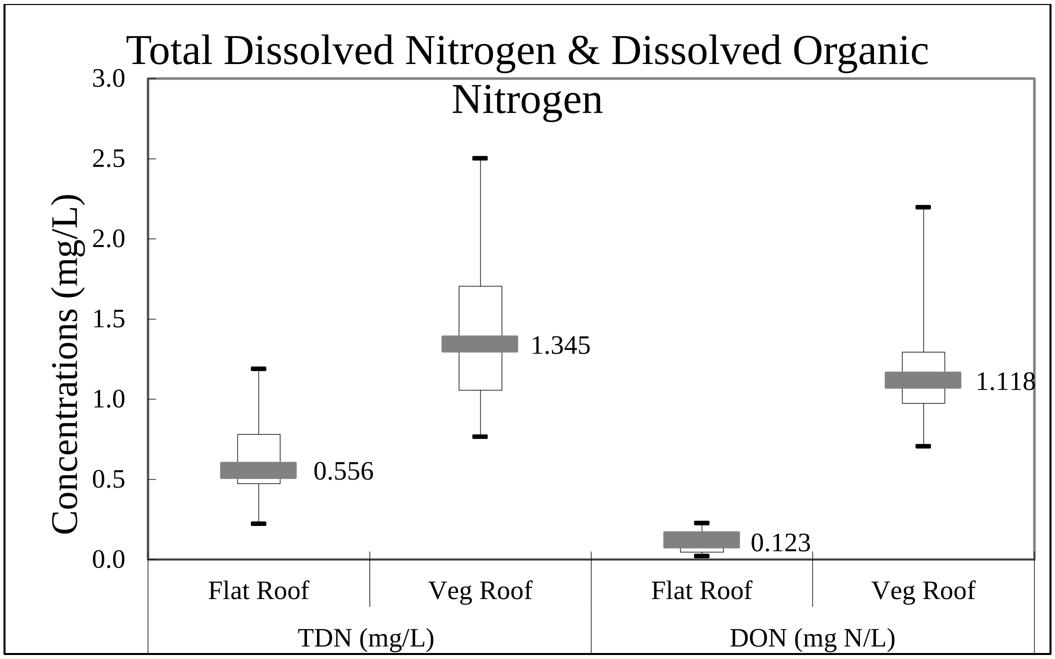


**Figure 3: Box and whisker plots of Total Dissolved Nitrogen (TDN) and Dissolved Organic Nitrogen (DON) results from conventional flat roof and vegetated green roof comparison study.**

**Table 4: Water quality monitoring results for the conventional flat roof and vegetated green roof including nitrate ($NO_3$) & nitrite ($NO_2$), ammonium ($NH_4$), phosphate ($PO_4$), and total phosphorus (TP) concentrations.**

| | NO3+NO2 (mg N/L) | | | NH4 (mg N/L) | | | PO4 (mg P/L) | | | TP (mg P/L) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Veg Roof | Flat Roof | RE% | Veg Roof | Flat Roof | RE% | Veg Roof | Flat Roof | RE% | Veg Roof | Flat Roof | RE% |
| 7/11/2013 | 0.543 | 0.428 | -27% | 0.075 | 0.281 | 73% | 0.605 | 0.002 | -30131% | 0.679 | 0.047 | -1347% |
| 7/23/2013 | 0.312 | 0.297 | -5% | 0.014 | 0.158 | 91% | 0.504 | 0.002 | -25084% | 0.576 | 0.022 | -2570% |
| 8/1/2013 | 0.289 | 0.230 | -26% | 0.016 | 0.094 | 83% | 0.377 | 0.002 | -20766% | 0.447 | 0.041 | -998% |
| 8/9/2013 | 0.033 | 0.102 | 68% | 0.033 | 0.076 | 56% | 0.441 | 0.005 | -9393% | 0.605 | 0.035 | -1631% |
| 9/12/2013 | 0.050 | 0.216 | 77% | 0.011 | 0.253 | 96% | 0.551 | 0.009 | -6174% | 0.578 | 0.004 | -15308% |
| 9/22/2013 | 0.019 | 0.058 | 68% | 0.011 | 0.053 | 79% | 0.426 | 0.017 | -2391% | 0.466 | 0.023 | -1947% |
| 10/6/2013 | 0.158 | 0.342 | 54% | 0.012 | 0.443 | 97% | 0.331 | 0.002 | -16456% | 0.347 | 0.023 | -1428% |
| 10/31/2013 | 0.240 | 0.527 | 54% | 0.010 | 0.640 | 98% | 0.278 | 0.002 | -13206% | 0.295 | 0.028 | -956% |
| | | | | | | | | | | | | |
| MIN | 0.019 | 0.058 | -27% | 0.010 | 0.053 | 56% | 0.278 | 0.002 | -30131% | 0.295 | 0.004 | -15308% |
| 25th Q | 0.046 | 0.188 | -10% | 0.011 | 0.090 | 78% | 0.366 | 0.002 | -21845% | 0.422 | 0.022 | -2103% |
| MEDIAN | 0.199 | 0.264 | 54% | 0.013 | 0.205 | 87% | 0.433 | 0.002 | -14831% | 0.521 | 0.025 | -1530% |
| AVERAGE | 0.206 | 0.275 | 33% | 0.023 | 0.250 | 84% | 0.439 | 0.005 | -15450% | 0.499 | 0.028 | -3273% |
| 75th Q | 0.295 | 0.364 | 68% | 0.020 | 0.322 | 96% | 0.515 | 0.006 | -8588% | 0.585 | 0.036 | -1260% |
| MAX | 0.543 | 0.527 | 77% | 0.075 | 0.640 | 98% | 0.605 | 0.017 | -2391% | 0.679 | 0.047 | -956% |

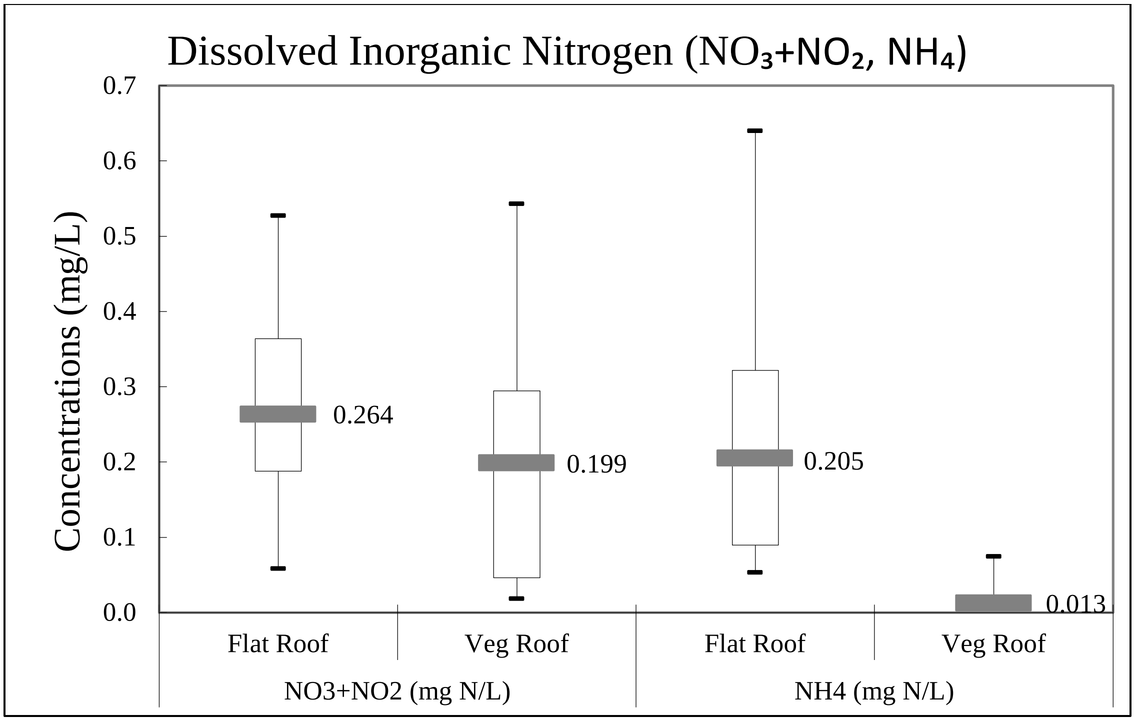


**Figure 4: Box and whisker plots of Nitrate + Nitrite ($NO_3$+$NO_2$) and Ammonium ($NH_4$) results from conventional flat roof and vegetated green roof comparison study.**

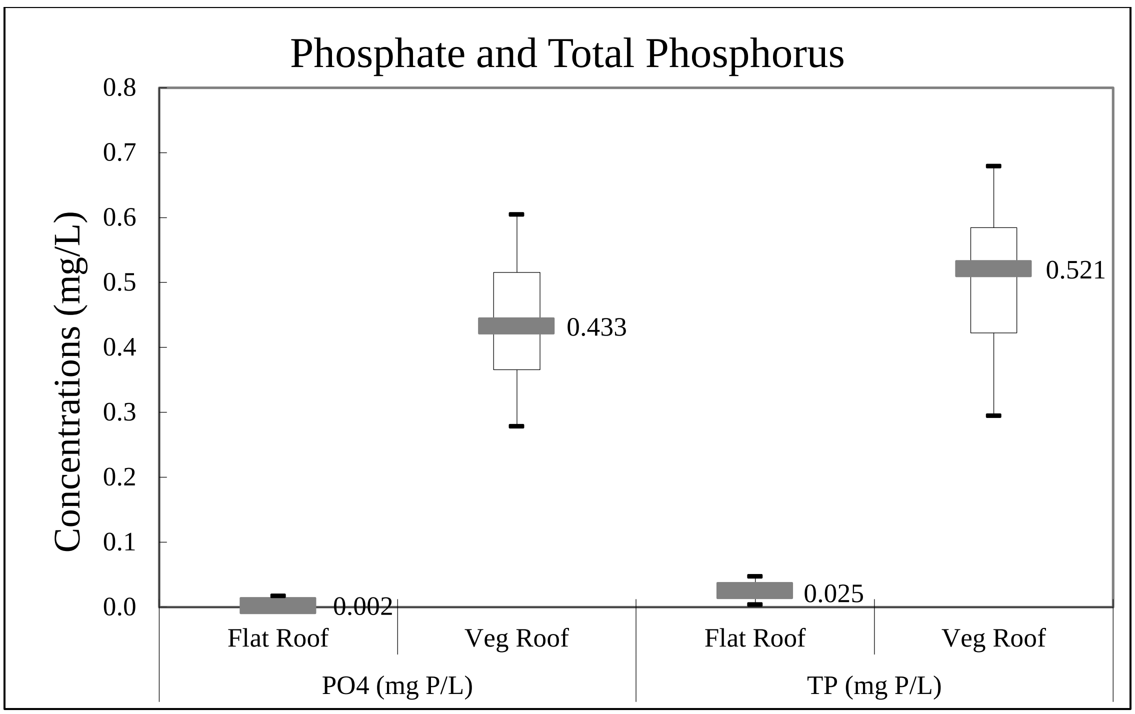


**Figure 5: Box and whisker plots of Phosphate ($PO_4$) and Total Phosphorus (TP) results from conventional flat roof and vegetated green roof comparison study.**

**Table 5: Real Time water quality monitoring results for the conventional flat roof and vegetated green roof including temperature, specific conductivity, dissolved oxygen and pH.**

| | Vegetated Roof | | | | Reference Roof | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Temp (°F) | Spec Cond (uS/cm) | DO (mg/l) | pH | Temp (°F) | Spec Cond (uS/cm) | DO (mg/l) | pH |
| 7/11/2013 | 53.9 | 0.072 | 12.72 | 6.14 | 60.8 | 0.023 | 5.9 | 5.18 |
| 7/23/2013 | 36.8 | 0.147 | 5.64 | 5.36 | 40.5 | 0.091 | 5.8 | 4.31 |
| 8/1/2013 | 65.15 | 0.074 | 1.55 | 4.94 | 64.41 | 0.008 | 2.21 | 4.78 |
| 8/9/2013 | 66.44 | 0.041 | 2.93 | 4.97 | 67.63 | 0.004 | 3.97 | 4.42 |
| 9/12/2013 | 68.04 | 0.044 | 8.31 | 5.59 | 72.57 | 0.018 | 7.98 | 4.14 |
| 9/22/2013 | 50.58 | 0.042 | 4.81 | 5.49 | 63.9 | 0.005 | 1.18 | 5.07 |
| 10/6/2013 | 68.47 | 0.066 | 8.01 | 6.13 | 67.05 | 0.033 | 8.62 | 4.73 |
| 10/31/2013 | 61.29 | 0.181 | 13.86 | 6.32 | 47.48 | 0.084 | 9.33 | 5.41 |
| 11/17/2013 | 50.32 | 0.136 | 7.84 | 5.84 | 43.2 | 0.012 | 6.46 | 5.4 |
| **median** | 61 | 0.072 | 7.84 | 5.59 | 64 | 0.018 | 5.90 | 4.78 |
| **average** | 58 | 0.089 | 7.30 | 5.64 | 59 | 0.031 | 5.72 | 4.83 |

The vegetative roof systems demonstrated buffering capacity for all measured real-time parameters, temperature, dissolved oxygen (DO) and pH measurements. Average effluent levels from the vegetated roof system were 1 degree F lower, 1.6 mg/L higher and 0.8 points higher respectively for the vegetated roof effluent all representing a positive movement in terms of water quality. The exception is the 0.058 uS/cm increase in the vegetated roof effluent which while still low signifies higher concentrations of ionic elements in the effluent compared to the reference runoff.

## Project Summary

The overall monitoring of the James Hall vegetated roof system and adjacent conventional rubber roof section was successful in attaining information to further the understanding of the non-point source nutrient removal capacity of these systems and their hydrologic functionality. The study provided consistent results for each parameter monitored thereby adding credibility to a relatively small data set. For water quantity parameters, the vegetated roof system demonstrated an average overall reduction in peak flows by 27%. There was no discernable runoff volume reduction which indicates that there is a need for consideration of aggregate depth and storage capacity within the vegetated roof cells to enhance volume reduction. The primary mechanism for volume reduction in vegetated roof systems is evapotranspiration (ET) which is a relatively slow process and likely minimal during precipitation events. Thus the vegetated roof system must have the reservoir capacity to store intercepted water volumes for a time period sufficient to allow ET to reduce the overall volume. The fact that antecedent dry period had no observable effect on volume reductions would indicate that the vegetated roof system lacks adequate storage capacity.  Overall the system demonstrated export of most parameters, but gave promising removals of DIN ($NO_3$, $NO_2$ and $NH_4$).  Water quality results demonstrate that consideration of aggregate type and selection of vegetative species may be important if water quality improvements are expected.  Selection of aggregate or growing media with higher cation exchange capacities (CAC) may be necessary to limit the mobilization of in-system positively charged organics such as phosphates.